Daniel Wójcik
Institute for Physical
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University of Maryland,
College Park, MD, 20742,
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12/10/2001

Dr. Chris Jarzyński
Los Alamos National Laboratory

Dear Dr. Jarzyński,

Following our e-mail correspondence I am sending you my application for a position at the Center for Nonlinear Studies or another available position at the Los Alamos National Laboratory.

I am a physicist interested in the theory and applications of nonlinear dynamics, both classical and quantum. I am currently working with Bob Dorfman on the connections between quantum chaos, quantum transport, and their classical limits. We study a toy model — quantum multibaker map — characterized by ballistic or localized transport depending on phases that specify the map.

One of the important issues in this connection is the role of decoherence in obtaining the semi-classical limit of the formulas connecting transport coefficients with chaotic parameters. The quantum multibaker model that we currently study allows a thorough and explicit analysis of this point. Another is the possible existence of quantum versions of fluctuation theorems on which you have also worked.

I worked on my thesis (*Fractal geometry in physical systems*) at the Center for Theoretical Physics of the Polish Academy of Sciences in Warsaw, Poland

and defended it at the University of Warsaw. My thesis advisor was Prof. Marek Kuś, I also worked there with Prof. Iwo Białynicki-Birula and Prof. Karol Życzkowski.

My current appointment terminates in June–August 2002, therefore I am looking for another position starting preferably between July 1st, 2002 and October 1st, 2002. Given my research interests and the current problems that I study, I believe that a stay in Los Alamos National Laboratory would be of great benefit for my development and I hope I would be able to enrich the research of the Laboratory.

There are at least three specialists at LANL whose research is of interest to me, these are Salman Habib, Wojciech Żurek, and yourself. I would be happy to be able to learn from and cooperate with them. I have a number of projects to work on my own but I would like to join one of your existing projects or start a new one.

Enclosed please find my curriculum vitae and the statement of research plans.

I have asked Profs. J. Robert Dorfman, Marek Kuś, Karol Życzkowski and Iwo Białynicki-Birula to write the reference letters for me.

If you need any further information, do not hesitate to contact me. Let me mention finally that I am sending similar letters to Drs. Salman Habib and Wojciech Żurek.

Sincerely Yours,

Daniel Wójcik

===

Iwo Bialynicki-Birula
Center for Theoretical Physics
Lotnikow 32/46
02-668 Warszawa, Poland
birula@cft.edu.pl   tel. +4822 8470920

Letter of recommendation for Daniel Wojcik

I have known Dr. Wojcik for more than five years, ever since he began
his work at our Center. I have had many scientific discussions with him
that resulted in our joint PRL on the fractal solutions of the
Schroedinger equation.=20
On the basis of all these contacts I have formed a highly favorable
opinion on his abilities to become a very successful theoretical
physicist. He has a very broad and sound training in mathematics and he
knows how to apply it to solve problems in physics. He is also very well
organized and has a clear view of his future research. I am sure that
if he is accepted at the CNLS he would be a creative member of that
group. I believe that his background and his present research interests
make him a very good candidate for this job.

UNIVERSITY OF
MARYLAND

INSTITUTE FOR PHYSICAL SCIENCE AND TECHNOLOGY

College Park, Maryland 20742-2431
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December 12, 2001

Dr. Chris Jarzynski
T-13, MS B213, LANL
Los Alamos, NM 87545

Chris

Dear Dr. Jarzynski:

Dr. Daniel Wojcik, a postdoctoral fellow working with me, has asked me to write this letter of reference in support of his application for a postdoctoral position at Los Alamos National Laboratory. I am happy to recommend him very highly to you.

Daniel came to work with me shortly after receiving his Ph.D. at the University of Warsaw with a thesis on a special class of solutions of Schrodinger's equation which are fractal. The possibility of such fractal solutions was first pointed out by Michael Berry. Daniel with co-workers in Warsaw, extended and amplified his work in a number of interesting directions, and provided mathematical proofs of some key results.

Daniel has been working with me for the past year on quantum chaos, a new subject for me, and in many ways a new subject for him as well. It took us some months to become familiar with the literature and to find a problem that we felt might be a rewarding one to study. Eventually we settled on a study of quantum baker maps, in particular, chains of baker maps that classically are known to exhibit diffusion, positive entropy production, and are essentially hyperbolic dynamical systems. The quantum baker map on a unit square has been well studied, of course, but the baker chain has not, at least not in the direction that is of most interest to us - the study of transport and entropy production as functions both of the value of Planck's constant, and of the degree of randomness that could be built into the system, by various means. We are well along in this study and anticipate a number of papers will result shortly from this work. The first one will be completed before the end of this year. That no paper has been submitted for publication until now is mainly the result of our, but most especially my, entrance into an essentially new field. I can tell you that Daniel has done some very, very smart things in the course of this work, and much of the richness of our results is directly due to his creative abilities. He took a rather simple and straightforward model and has made it into a very flexible systems that exhibits all kinds of interesting, and in many ways surprising phenomena.

Daniel Wojcik is an extremely mature and gifted young theorist. I can honestly say that working with him has been an unalloyed pleasure. He has a broad knowledge of physics and mathematics, excellent computer skills, but most importantly from my perspective, he has an adult appreciation of science and how research should be carried out. There is no need to worry about personality clashes, since he instinctively knows how to approach a problem and how hard one must work to get serious results. In this way he has been among the most congenial of all of my post-docs, and as bright as any, with only one exception, Henk van Beijeren, the deepest thinker among the several

physicists with whom I've had the opportunity to work. Daniel, like Rainer Klages, a former student now at MPIPKS, is certainly capable of work of a similar high quality.

I can recommend him to you with sincere enthusiasm, and hope that you will be able to find a place for him at Los Alamos. I think your Laboratory is the right place for him at this stage in his career, and both you and he would be very happy with the fruitful scientific collaborations that would result from such an appointment.

With best regards,

J. R. Dorfman, Professor
Department of Physics and
Institute for Physical Science and Technology

JRD:jp

December 19, 2001

To the CNLS postdoc committee:

Enclosed with this cover letter is an application for a postdoctoral position by Daniel Wójcik, currently at the University of Maryland.

Dr. Wójcik comes strongly recommended by Professor J. Robert Dorfman at Maryland (see attached letter); further recommendations will be forwarded to CNLS as they arrive. His primary interests lie in the field of nonlinear dynamics, especially at the interface of the quantal and classical worlds. Specific topics of interest include the role of decoherence in the quantum-classical transition, and the possibility of obtaining a quantal version of the fluctuation theorem and related far-from-equilibrium results. Both areas have been the subject of intense theoretical and experimental investigation over the past decade, and both provide strong overlap with the interests of T-division members such as Wojciech Zurek (T-6), Salman Habib (T-8), and myself (T-13).

In addition to his research, Dr. Wójcik has been actively engaged in the broader community of scientists, as witnessed by his leadership in university student groups, in his promotion of science among gifted children, and in the international array of conferences, workshops, and schools which he has attended. I believe he would make an excellent addition to the talented pool of postdocs at the CNLS, and have arranged for him to visit here in mid-January.

Please contact me if there is any more information which I could provide to further Dr. Wójcik's application.

With best regards,

Christopher Jarzynski

5-3887
chrisj@lanl.gov

center for theoretical physics

POLISH ACADEMY OF SCIENCES

Al. Lotników 32/46
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Dr. MAREK KUŚ

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Dr Chris Jarzynski
T-13, MS B213
Los Alamos National Laboratory
Los Alamos, NM 87545

Warszawa, 18.12.2001

Dear Chris,

I am writing in behalf of my former Ph. D. student, dr Daniel Wójcik, who applies for a postdoctoral position in your group.
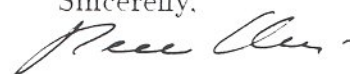
I have been knowing Daniel for about five years, from the time when he obtained the M. Sc. degree from the University of Warsaw and started working on his Ph. D. thesis under my supervision. His Ph. D. thesis was devoted to applications of fractal geometries to classical and quantum problems. The main and most important results of his investigations were: 1) a method of characterizing various interaction between two classical subsystems in terms of attractor dimensions, 2) construction of fractal wavefunctions of non-chaotic Schrödinger equations. Since he will probably report on his scientific achievements in a more detailed way in his application, let me only say that his Ph.D. thesis was awarded a distinction and the main results were published in *Physical Review Letters* and *Physical Review*. As a supervisor I find Daniel being among the top 5% of students finishing their Ph. D. each year, and in fact the most gifted and promising student I have had.

Last year he spent in the Institute for Physical Science and Technology, at the University of Maryland in College Park, working in the group of Robert Dorfman on quantum maps.

I would like to stress in this recommendation other features qualifying Daniel, in my opinion, as an excellent future researcher. He is a very active participant and organizer of seminars, meetings etc. This gives him opportunities to present his results and attract other to common projects - in fact, he initiated a fruitful cooperation with an experimental group at the Institute of Physics of Polish Academy of Sciences in order to verify his theoretical findings. He has also a solid teaching experience as a teaching assistant in the School of Sciences at the Polish Academy of Sciences in various areas of mathematics and theoretical physics, as well as a devoted popularizer of sciences among high-school students.

Summarizing I wholeheartedly recommend Daniel Wójcik for the postdoctoral position, being sure the he will contribute a lot to the local scientific community.

Sincerelly,

Marek Kuś

Prof. Karol Życzkowski   Warszawa, December 10, 2001
Center for Theoretical Physics
Polish Academy of Science
Al. Lotników 32/46; 02-668 Warszawa, Poland
email: karol@cft.edu.pl

                          Dr. Chris Jarzynski

                          T-13, MS B213,

                          Los Alamos National Laboratory

   Ref: application of Dr. D. Wójcik

Dear Chris,

This is a letter of recommendation for dr Daniel Wójcik, who is applying for a post-doc
position at your Institute.

I know dr Wójcik personally from summer 1997, as he started his Ph.D studies at Center
for Theoretical Physics in Warsaw. Although he was Ph.D student of Prof. Marek Kuś,
we have had a two-years fruitful collaboration which resulted in two papers on fractal
solutions of the Schrödinger equation. One of these was published in Physical Review
Letters in 2000 with Dr. Wójcik as the first author.

In my opinion Dr Wójcik was one of the best Ph.D students, which received the degree
in theoretical physics in Poland during last five years. I was amazed by his knowledge
of the theory of dynamical systems and the ease to pose physically interesting questions
and to solve them. He knows mathematical and physical literature in the field of chaos,
quantum chaos, and the theory of nonlinear systems, and he knows how to make use of
this knowledge. Working on his thesis he proved to be a competent and an independent
researcher. Honestly speaking, I was always regretting, he was not *mine* Ph.D student.

I am convinced he will be able to continue his scientific career in theoretical physics and
applied mathematics and I believe, he is a very good candidate for a post doc to any
Institute, in which research in this field is pursued. In particular, he could contribute to
the activities developed by Theory Department of the Los Alamos National Laboratory.

Yours Sincerely

Karol Życzkowski

Curriculum Vitae

Daniel Krzysztof Wójcik

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Greenbelt, MD 20770
USA

tel: (301) 474 0716

Born: August 16th, 1973, Radom, Poland.

EDUCATION

University of Warsaw,   October 2000
   Philosophy Degree (with distinction)
   Thesis title: "Fractal geometry in physical systems"
   Thesis advisor: Prof. dr hab. Marek Kuś

University of Warsaw,   June 1996
   Masters of Science (with distinction)
   Thesis title: "Reductions of Self-Dual Yang-Mills Equations"
   Thesis advisor: Dr hab. Jacek Tafel

SCHOLARSHIPS

Merit Scholarship of the Polish Ministry of Education   1993 – 1996
Polish National Children's Fund Merit Scholarship   1987 – 1991

EMPLOYMENT

Institute for Physical Science and Technology, University of Maryland
College Park, Maryland, USA
   Research Associate with Dr. J. Robert Dorfman   November 2000 – present

Center for Theoretical Physics, Polish Academy of Sciences,
Warsaw, Poland
   Research Assistant   June 1996 – October 2000
   On leave   November 2000 – present

Department of Physics, University of Warsaw
Warsaw, Poland
   Teaching Assistant   October 1994 – June 1996

1

Deutsches Elektronen Synchrotron
Hamburg, Germany
Summer Student   Summer 1993

RESEARCH AND SCHOLARLY ACTIVITIES

SHORT SCIENTIFIC VISITS
Max Planck Gesselschaft Arbeitsgruppe,   July 1993
    Jena, Germany, (R. Meinel, G. Neugebauer)
Max Planck Gesselschaft Arbeitsgruppe,   December 1996
    Jena, Germany, (R. Meinel, G. Neugebauer)   (seminar)
University of New Mexico,   January 2000
    Albuquerque, USA, (N. Kenkre)   (seminar)
University of Texas,   January 2000
    Austin, USA, (H. Swinney)   (seminar)
George Mason University,   January 2000
    Fairfax, Virginia, USA, (P. So)   (seminar)
University of Maryland,   January 2000
    College Park, USA, (J. R. Dorfman)   (seminar)

RESEARCH FUNDING
Polish State Committee for Scientific Research: January - December 1999
    Junior Grant ($2800, Primary Investigator)

CONFERENCES, WORKSHOPS, SUMMER AND WINTER SCHOOLS
Deutsches Elektronen Synchrotron,   July-August 1993.
    Hamburg, Germany, summer school
"Let's Face Chaos through Nonlinear Dynamics",   September 1993
    Ljubljana, Slovenia, summer school
"Differentialgeometrie und Quantenphysik"   March 1994
    Międzyzdroje, Poland, winter school
"Chaos, the interplay between stochastic,   February 1995
    classic and quanta", Karpacz, Poland, winter school
"First Non-orthodox School on Nonlinearity   September 1995
    and Geometry", Warsaw, Poland, workshop
"Singularity Theory and real analytic geometry",   January 1997
    Zakopane, Poland, winter school   (oral)
"Dynamics Days 1999",   June 1999,
    Italy, Como, conference   (oral)
"Holomorphic Dynamics, Conformal   November 1999
    and Invariant Measures", Warszawa, Poland, workshop
"Dynamics Days 2000",   January 2000,
    Santa Fe, USA, conference   (poster)
"84th Statistical Mechanics Conference",   December 2000
    Rutgers, USA, conference
"Dynamics Days 2001",   January 2001,
    Chapel Hill, USA, conference   (poster)

"Semi-annual Workshop on Dynamical Systems and Related Topics", College Park, USA, workshop	March 2001
"Quantum Chaos: Theory and Applications" Cocoyoc, Mexico, conference	July 2001 (poster)
"The Mathematical aspects of Quantum Chaos I" Bologna, Italy, summer school	September 2001 (oral)
"Dynamics Days 2002", Baltimore, USA, conference	January 2002, (poster)
"Dynamical Semigroups: Dissipation, Chaos, Quanta" Karpacz, Poland, winter school	February 2002 (poster)
"Semi-annual Workshop on Dynamical Systems and Related Topics", College Park, USA, workshop	March 2002

PUBLICATIONS

D. **Wójcik** and J. R. Dorfman, *Quantum multibaker maps I: Large ℏ case,* in preparation.

D. **Wójcik** and K. Życzkowski *Fractality of certain quantum states,* preprint math-ph/0107030

D. **Wójcik**, A. Nowak, M. Kuś *Extracting dynamics of interaction,* Phys. Rev. E, **63** (2001) 03621.

D. **Wójcik**, I. Białynicki-Birula and K. Życzkowski *Time Evolution of Quantum Fractals,* Phys. Rev. Lett. **85** (2000) 5022.

J. Tafel and D. **Wójcik** *Null Killing vectors and reductions of the self-duality equations,* Nonlinearity 11 (1998) 835–844.

D. **Wójcik**, J. Cieśliński (ed.) *Proceedings of the First Non-orthodox School on Nonlinearity and Geometry. Luigi Bianchi Days,* Polish Scientific Publishers 1998, ISBN 83-01-12642-6.

D. **Wójcik**, *Symmetries of differential equations,,* Bulletin of the Student Nonlinear Physics Research Group, **1** (1995) 11–27. ISSN 1234-4052.

TEACHING EXPERIENCE

College of Science, Warsaw, Poland	October 1996 – February 2000

Teaching Assistant (mathematical analysis, introduction to theoretical physics, nonlinear dynamics, statistical physics)

Guest lectures during the courses
— nonlinear dynamics: time series analysis
— mathematical analysis: multidimensional differential and integral calculus
— statistical mechanics: ergodic theory and irreversibility

University of Warsaw, Department of Physics	October 1994 – June 1996

Teaching Assistant (mathematical analysis)

SERVICES

Center for Theoretical Physics, PAS	1999 – 2002

a member and the Secretary of the Scientific Council (young staff representative)

University of Warsaw, Department of Physics, vice-president of the students self-government	1992/3

member of the Program Board of the Department of Physics
(students representative)
Student Nonlinear Physics Research Group (SNPRG),
    University of Warsaw, Department of Physics,
    co-founder and the first President of SNPRG   1993/4-1994/5
    editor of the first Bulletin and Editor in Chief of the second issue
"First Non-orthodox School on Nonlinearity   September 1995
    and Geometry", Warsaw, Poland, a co-organizer,
    the Secretary and a co-editor of the Proceedings
Polish National Children's Fund   1992 – 2000
    cooperation in programs for gifted children:
    — two workshops organized during scientific camps of PNCF,
    — "Seize the chaos", on nonlinear time series analysis
    — "Sand-piles", on the properties of piles of granular materials
    — deputy of the camp's director   May 1999
    — a referee in the selection process of scholarship candidates
Seminars coordinator and coorganizer
    seminar of the SNPRG   1993 – 1995
    seminar of the Center for Theoretical Physics   1997 – 2000
    "Chaos and non-equilibrium statistical mechanics"   1998 – 2000
    "Chaos and non-linear dynamics"   1999 – 2000

Current as of December 10th, 2001.

Present research and the future plans: the main and some secondary projects

Daniel Krzysztof Wójcik

December 4, 2001

1 Models of Quantum Transport

Classical extended systems are often characterized by diffusive dynamics. For instance, in Lorentz gases the motion of the tracer particle is diffusive whether the scatterers are distributed randomly or on the lattice [7, 3] (I assume here finite horizon). On the other hand, in quantum mechanics one expects localization and sub-diffusive dynamics for a random Lorentz gas, and ballistic motion with extended states for the regular system [2, 5].

1. How is the diffusive behavior achieved in the semi-classical limit in regular and in random systems?

2. What happens to the classical formulas connecting transport coefficients to Lyapunov exponents, Kolmogorov-Sinai entropy, fractal dimensions of hydrodynamic modes [4] when one quantizes a classically chaotic diffusive system? Should one look for quantum corrections or rather try to use quantum characteristic exponents and entropies [1]? What is the role of decoherence in recovering these formulas in the semiclassical limit?

3. How is the type of classical dynamics (chaotic, regular) reflected in the quantum transport properties, approach to equilibrium, entropy production rate? What is the difference between the random and regular cases having the same classical limit?

4. Semi-classical correlation functions show signatures of Ruelle-Pollicott resonances (Sridhar, Stöckmann). Can one define in a physically meaningful way quantum resonances which go over into the classical ones in the appropriate limit?

5. What is the entropy production in quantum extended systems? Does one need infinite systems for positive entropy production?

The ultimate goal is understanding quantum fluids. In order to find out appropriate tools we precede their studies by analysis of simple models, first quantum maps, then quantum Lorentz gases. Currently these questions are studied in quantum multibaker maps and Lorentz gases.

Quantum multibaker maps are a family of Weyl quantizations of classical multibaker maps and are toy models of quantum random walk in one dimension. Depending on the properties of the phases parametrizing quantization, the QMB maps can be divided into two classes: regular and random. We have studied the one-dimensional case with large $\hbar$. Regular QMB maps have extended eigenstates and exhibit ballistic transport. Random QMB maps have localized eigenstates and sub-diffusive transport.

In the regular case we obtained analytic solutions for periodic and absorbing boundary conditions. Steady state solutions and relaxation to steady state for regular QMB in contact with "particle" reservoirs have also been obtained explicitly. These analytical results were confirmed by computer analyses, and contrasted with numerical findings in the random case [11].

The next steps will be

1. The study of the semi-classical limit in one-dimensional quantum multibakers.

2. Two-dimensional generalization: we expect weak localization. Is it there?

3. Three-dimensional case: here one expects that only some of the eigenstates would be localized, the other should be extended. Is there a clear division of the spectrum into localized and extended states? (Are there mobility edges?) This problem is different from those usually studied in that the spectrum lies on the unit circle, thus one does not have lower bound on the energy.

4. Quantum fluctuation theorem: What is the connection between the probability of positive and negative entropy production rate? Can one obtain similar formulas as in the classical case (Gallavotti, Cohen, Maes, Kurchan, Jarzyński, etc.)? Is there any difference between the regular and random case?

5. Semi-classical Lorentz gas, two-dimensional, regular and random: the search for traces of classical formulas.

2 Fluctuation theorems

In 1995 Gallavotti and Cohen found a connection between the probabilities of positive and negative entropy production in hyperbolic Gaussian thermostated systems. Similar results for other systems were found by Maes, Kurchan, Crooks, Jarzyński, Lebowitz, Spohn, Evans, Searless . There are several numerical works confirming these findings, notably by Evans, Searless and Isbister. It seems, however, that no experimental confirmation is yet available. We are currently involved in the discussion and analysis of possible experimental schemes of verifying these theorems intended by Wolfgang Losert and his group at University of Maryland.

The quantum fluctuation theorems have received much less attention. Apart from the work of Kurchan (cond-mat/0007360) there does not seem to be any serious work on the

topic (note however the works of Jaksić and Pillet, and of Ruelle, on entropy production of infinite quantum spin systems). Our toy quantum model (quantum multibaker map) enables us to study the fluctuations of entropy production in detail, both in the deep quantum regime and in the semi-classical limit. The results can be compared with those for the classical multibaker maps. We hope these studies would guide us in understanding entropy production for more realistic quantum systems.

3 Quantum hyperbolic systems

By quantum chaos or chaology one usually means the study of semi-classical behavior of quantum systems which are classically chaotic. Classical chaos is usually connected with positivity of certain indicators such as characteristic exponents or KS entropy. Is it possible to explain the rise of these indicators in the classical limit with the help of some quantum indicators?

The natural approach is to study phase-space representations of density-matrices. The Husimi distribution approach was pursued by Haake, Życzkowski et al.. Mańko and Vilela-Mendes have recently discussed the approach through Wigner functions. Other interesting works include Thirring, Emch, Majewski and Alicki and Fannes (see [1] for a review).

Among the most promising quantum entropies is the Alicki-Fannes entropy [1]. It seems to lead to the KS entropy if one takes the limits in a well-defined order (F. Benatti et al., private communication). What is missing in these studies is quantitative estimate of how do the quantum notions tend to their classical counterparts in the semi-classical limit.

We believe that one needs to find a function of time and Planck constant $\lambda(t, \hbar)$ which gives the classical Lyapunov exponent in the limit $\lim_{t \to \infty} \lim_{\hbar \to 0} \lambda(t, \hbar)$ and study its quantum behavior. Preferably one would like to recover the whole spectrum. This is unknown. One might expect $\lim_{t \to \infty} \lambda(t, \hbar) = 0$, but then the question is how fast is the approach to 0, what are the finite time corrections in $\hbar$ to characteristic exponents and are they reflected for instance in the transport formulas, escape formulas, Pesin equality.

It is possible that no such reasonable function can be devised and one needs decoherence in order to account for the rise of positive Lyapunov exponents. This is the claim of Salman Habib, Juan Pablo Paz, Wojciech Żurek.

4 Dissipative baker maps

The Weyl quantization of simple conservative maps is relatively well understood (Berry, Keating, Degli Esposti, de Bievre). Can one find a "quantization" procedure for dissipative maps? The procedures used so far include either idealizations of interaction with some heat bath (Graham, Braun, Haake, etc.) or ad hoc procedures (e.g. quantization of the horseshoe by Saraceno and Vallejos).

We are interested in developing a general approach but a model system with which we start is a version of classical baker map. We take the time-reversible version which

expands the volume of one part and contracts the other part of the system. This is a caricature of classical thermostated systems thus the solution of this problem would shine some light on the possibility of finding "cheap" thermostats in quantum theory. Note that there is a Hamiltonian reformulation of thermostated dynamics (Dettmann) but it is local (Wojtkowski) and thus it probably does not admit a quantization.

5   Approach to equilibrium in quantum conservative systems

It is a foundation of thermodynamics that an isolated system arrives at equilibrium if left alone. This seems to contradict the conservation of Gibbs and Von Neumann entropies. One way to avoid a contradiction is to assume some interaction with the environment. In our opinion this is not necessary. True, there is no completely isolated system, but the hard sphere gas would equilibrate even without outside perturbations.

What we seek is a microscopic theory of non-equilibrium thermodynamics for isolated conservative quantum systems. The importance of these problems have also been discussed in the epilogue to the book by Alicki and Fannes. Let us mention also Srednicki's work which used the Berry conjecture to justify the equilibrium theory in the semi-classical limit.

Before building a general quantum theory we want to understand its framework on toy models. Quantum multibaker maps afford here a simple to implement models showing rich behavior ranging from fast equilibration in the regular systems to glass-like jamming in the random version having also a well understood classical limit.

6   Quantum fractals

We have constructed a family of fractal solutions to the Schrödinger equation with power-law potentials in one dimension [8]. We chose them for the sake of simplicity of the proofs [10], however, we believe that 1) these sorts of solutions are generic in high energy limit, 2) most bound systems preserves this sort of fractal structure. Of course, for any finite energy the solution is not a true fractal but it can be a "physical fractal", i.e. exhibit approximate scaling through a range of scales. The notion needs to be made precise. The generalization to n dimensions is straight-forward.

Our solutions are fractal functions but as measures they do not have fractal character. It is however possible to construct a solution to the Schrödinger equation which would constitute a multifractal measure $|\Psi|^2$. However, the multifractal character does not seem to be preserved by the dynamics for the potentials we considered. Can one find potentials that preserve the multifractal character of the probability density?

Can one find quantum systems that naturally develop fractal structures? These would probably be open, driven systems, because the energy of the solution would have to increase (every additional scale means energy increase).

Similar theory can be worked out for electromagnetic systems, in particular microwave resonators. Of course, the connection between time and space fractal dimensions would be different than in quantum mechanics but it is a simple detail.

Can one realize our solutions experimentally? The most promising systems are heavy atoms or ions in traps or microwave cavities. One needs to calculate the possible ranges of frequencies that can be bound inside a trap.

7 Interacting versus non-interacting subsystems

Consider a spatially extended dynamical system, such as brain or fluid sample. Suppose one gathers simultaneously time series of certain variables in the sample. How can one characterize the interactions among different parts? The natural approach is to look at the cross-correlations but it leads sometimes to contradictory results (A. Nowak, A. Wróbel). Thus alternative methods have been proposed. People analyzed fractal dimensions of reconstructed attractors [9], used synchronization approach [6] and even quantum chaos (P. Šeba, private communication). It is of interest, especially in the neuroscience community, to compare the effectiveness and precision of these methods as well as generalize them to allow for non-stationarity of the system. A comparison of the available methods in models and real systems is intended in the future depending on the accessible time, available students and interested experimentalists.

References

[1] R. Alicki and M. Fannes. *Quantum dynamical systems*. Oxford Univ. Press, Oxford, 2001.

[2] N. W. Ashcroft and N. D. Mermin. *Solid State Physics*. Holt, Rinehart and Winston, New York, 1976.

[3] L. A. Bunimovich. Existence of transport coefficients. In D. Szász, editor, *Hard Ball Systems and the Lorentz Gas*, volume 101 of *Encyclopaedia of Mathematical Sciences*, pages 145–178. Springer Verlag, 2000.

[4] J. R. Dorfman. *An introduction to chaos in nonequilibrium statistical mechanics*. Cambridge University Press, Cambridge, 1999.

[5] D. K. Ferry and S. M. Goodnick. *Transport in Nanostructures*. Cambridge University Press, Cambridge, 1997.

[6] S. J. Schiff, P. So, T. Chang, R. E. Burke, and T. Sauer. Detecting dynamical interdependence and generalized synchrony through mutual prediction in a neural ensemble. *Phys. Rev. E*, 54(6):6708–6724, December 1996.

[7] H. van Beijeren. Transport properties of stochastic Lorentz models. *Rev. Mod. Phys.*, 54(1):195–234, 1982.

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[9] D. Wójcik, A. Nowak, and M. Kuś. Dimension of interaction dynamics. *Phys. Rev. E*, 63:036221, 2001.

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-- CNLS talk

Quantum Multibaker - A Deterministic Model of a Quantum Random Walk

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14 January 2002, Monday from 2:00 PM to 3:00 PM

CNLS Conference Room

We introduce a family of models for quantum mechanical, one-dimensional random walks, called quantum multibaker maps (QMB). These are Weyl quantizations of classical multibaker models previously considered by Gaspard, Tasaki and others. Depending on the properties of the phases parametrizing the quantization, the QMB maps can be divided into two classes: regular and random. Regular QMB maps are characterized by phases which are the same in every unit cell of the multibaker chain. They have spatially extended eigenstates and exhibit ballistic transport. Random QMB maps have phases that vary randomly from unit cell to unit cell. They have localized eigenstates and exhibit subdiffusive transport. In the regular case and for large r, analytic solutions can be obtained for the time dependent quantum states for periodic chains and for open chains with absorbing boundary conditions. Steady state solutions and the properties of the relaxation to a steady state for regular QMB chain in contact with ``particle" reservoirs can also be described analytically. The analytical results obtained here are confirmed by computer analyses, and contrasted with numerical findings in the random case. We present the results for the deep quantum case (large r).

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